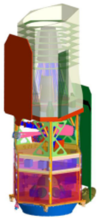


Image quality for WL: engineering comments

- Outline
  - 1 [pp. 2-5]. Recap of discussion Neil/Paul/Dave on unobscured trade pros and cons [action on me: turn my notes into ppt]
  - 2. [pp. 6-16] Ellipticity comparison of J-Omega v. 4c3 [Lehan working this but initial draft is here]
  - 3. [pp. 17-22] Discussion of pointing & guiding architecture for WL [Kruk]

Telecon w/ Schechter and Gehrels

- Goal – clarify the concerns on the unobscured aperture telescope alternative to Omega
- Context is enabling WL observations that meet the need for exquisite stability
- Requirements on ellipticity:
  - Drift in ellipticity as a function of time – need to be stable during an observation
  - Change in ellipticity across the field
  - Rms ellipticity static across the field would be ideal (ie stable in time and with field angle) [also ideally, only psf chromatic variation is diffraction scaling w/ λ]
- Design includes a slower PM vs. JΩ

Design considerations for WL imaging

- Consensus is to avoid refractive cameras for WL imaging
- Short term AI: How many psf calibration stars can we expect in a WL exposure [SDT] – answer from quick look by Rhodes is >900
  - We can expect more bright stars than CCD observations, e.g. COSMOS, because of s/w to avoid saturated H2RG pixels
- Short term AI: document variation across the field in static intrinsic ellipticity, compare Omega to candidate uTMA design
  - Below, pp, 6-15
- PS: Hubble ellipticity varies across the field 0.1 – this is certainly too much.

HST performance v. WFIRST

- Discussion of HST thermal and jitter performance vs. WFIRST expectations
  - HST has 15 degree C axial gradient changes, unacceptable focus variability compared to WL stability requirements;
  - HST jitter and drift are low (4 mas) and it may be challenging to be sure we will get nearly this low on a lighter, cheaper observatory. No question it can be done with enough $. [see pointing/guiding presentation below]
- Thermal instability of HST largely due to its low orbit and operational constraints, e.g. Earth-pointing during portions of orbit when targets out of CVZ (continuous viewing zone) go behind the earth.
- Also more modern construction techniques that all were demonstrated on Chandra should be used on WFIRST. Chandra thermal stability of 0.2 degree (gradient stability) is ~ 2 orders of magnitude better than the 15 degree gradient instability observed on HST.
- Detailed pitch on HST performance v. WFIRST expectations is available

Jitter considerations

- Jitter may be constant across field
  - but given that our field is much larger than others, this would need to be shown through modeling
- PS agrees that the imaging performance of the uTMA is a strong argument for its use (e.g. the EE50 comparison Hirata showed at the SDT3 telecon).
- Another consideration is the additional ellipticity uncertainty we have seen introduced by PSFs with spider diffraction.
- Longer term action items:
  - SDT needs to help flow down the WL stability requirements towards engineering stability requirements
  - Project needs to continue to update predicted stability, integrated modeling required.
  - Project should share charts on TMA heritage with SDT [in backup of project presentation on uTMA trade space & design 4c3]

PSF ellipticity: a comparison of an obscured and unobscured point design for the SDT weak lensing subgroup

J. P. Lehan

May 6, 2011

Overview

- Compare obscured design to unobscured
- Obscured: JDEM Omega
- Unobscured: Option 4c3 (focal imager as similar to JDEM Omega as practical)
- Use direct pupil integration so we can chose image plane sampling

  Pupil sampling: 512x512

  Image sampling: 512x512 (1.75 um spacing)

  Field sampling: 3x3 [only middle point is inside perimeter, so a quick, conservative look]
- 0.23 arc-sec gaussian galaxy (full width 1/e max size)

Ellipticity metric definitions

$$e1 = \frac{P_{xx}}{P_{xx} + P_{yy}}$$

$$e2 = \frac{P_{xy}}{P_{xx} + P_{yy}}$$

For a circular image
e1=0.5, e2=0

$$P_{xx} = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}(x - \langle x \rangle)^2 \; W(x, y) * PSF(x, y) \, dx \, dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \; W(x, y) \, dx \, dy}$$

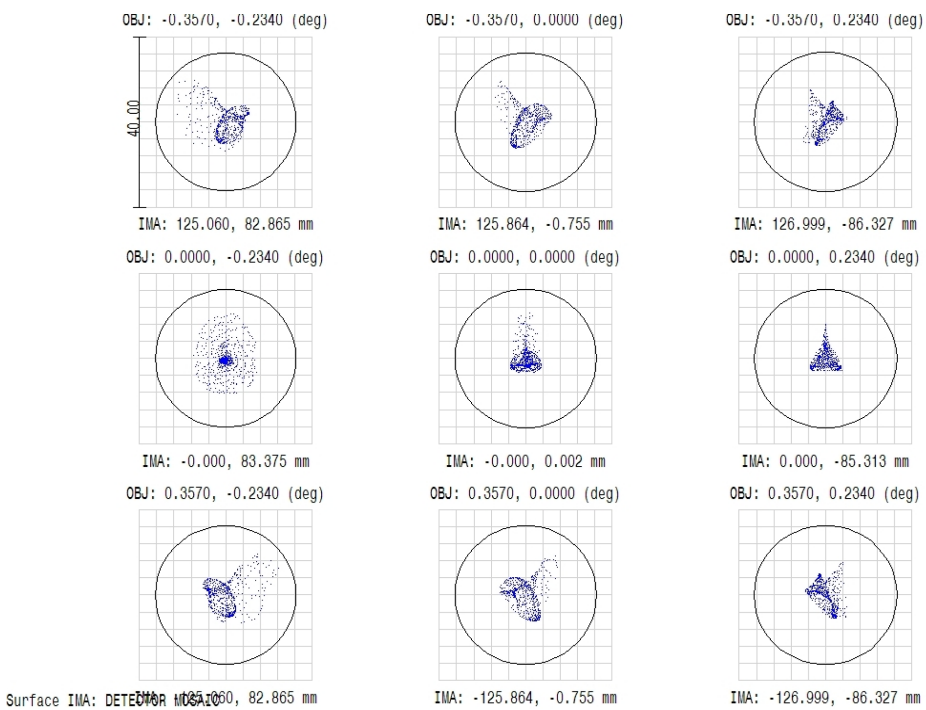
$$P_{yy} = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}(y - \langle y \rangle)^2 \; W(x, y) * PSF(x, y) \, dx \, dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \; W(x, y) \, dx \, dy}$$

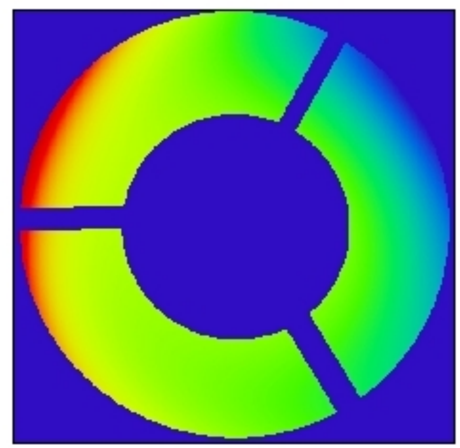
$$P_{xy} = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}(x - \langle x \rangle)(y - \langle y \rangle) \, W(x, y) * PSF(x, y) \, dx \, dy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \; W(x, y) \, dx \, dy}$$

where $\langle x \rangle$, $\langle y \rangle$ are the first moments, $W(x, y)$ is the weighting function (here a gaussian "galaxy"), and $*$ represents the convolution operation.

Omega simulation details

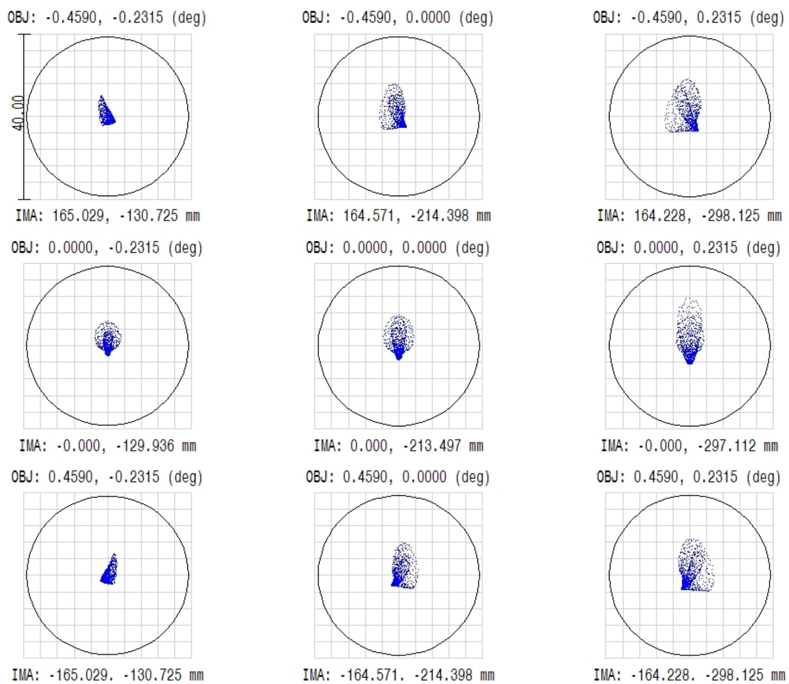
- Spiders and cold-stop mask (Mentzell Sim 4-2011)
- Nominal focus (F/#)
- Uses nominal detector position and orientation
- Accounts for focal plane obliquity (14.254º)

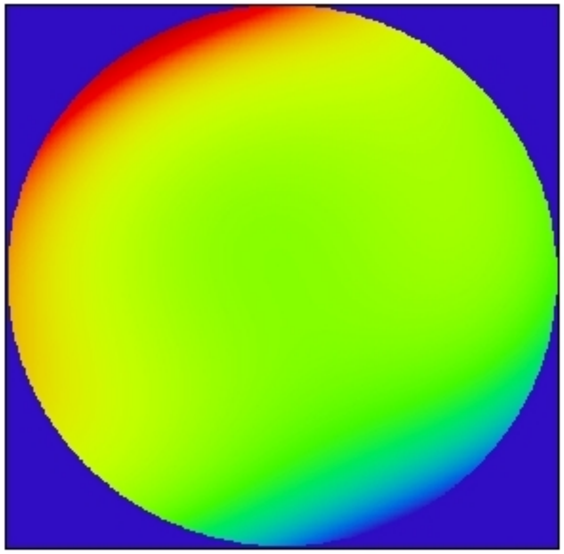




Option 4c3 simulation details

- No spiders or cold mask
- Accounts for exit pupil shape
- Nominal focus (F/#)
- Uses nominal detector position and orientation
- Accounts for focal plane obliquity (10.924°)





Variations with field

e1

Obscured

x/y	-0.357	0.0	0.357
0.234	0.513353	0.512823	0.511992
0.0	0.509292	0.509570	0.509404
-0.234	0.511566	0.510974	0.510296

e1 ave = 0.5110±.0015

Unobscured

x/y	-0.459	0.0	0.459
0.2315	0.508732	0.505299	0.501826
0.0	0.507902	0.506246	0.500314
-0.2315	0.507704	0.504514	0.501205

e1 ave = 0.5049±.0031

e2

Obscured

x/y	-0.357	0.0	0.357
0.234	-1.08e-3	-5.30e-3	-9.70e-3
0.0	-3.31e-3	-2.90e-3	-4.33e-3
-0.234	-4.90e-3	-2.85e-3	1.39e-3

e2 ave = (-3.66 ±3.06)x10-3

Unobscured

x/y	-0.459	0.0	0.459
0.2315	-1.06e-4	-8.60e-4	-5.50e-4
0.0	-9.60e-5	2.91e-4	2.62e-4
-0.2315	1.34e-4	6.18e-4	8.87e-4

e2 ave = (-0.422 ±6.624) x10-4

Field in object space degrees

summary

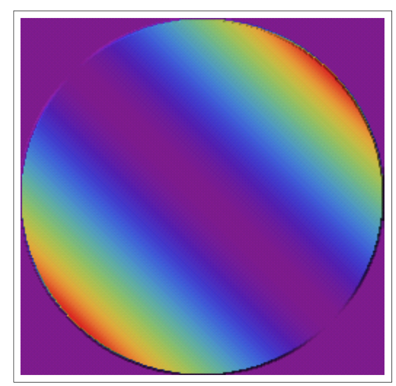
- Ellipticity of 4c3 design residuals is closer to ideal than that from JΩ design residuals
- “excess” in metric for 4c3 from ideal is roughly half of that for JΩ
- True using e,e1,e2 metric or invariant metric (in backup)

Extra Material follows

Lehan metric Є

- Motivation: SNAP metrics assume a preferred orientation in space (x and y). True for array but not nature.
- One number metric for ellipticity
- Pxx, Pyy, Px+y, Px-y all geometrically-equivalent
- Є ~ 1-(RMS deviation from RMS average 2nd moment)
- Є = 1 for perfectly circular PSF
- *Pij* is RMS spatial average 2nd moment

Px+y



$$\epsilon = 1 - \frac{\sqrt{(P_{xx} - P_{ij})^2 + (P_{yy} - P_{ij})^2 + (P_{x+y} - P_{ij})^2 + (P_{x-y} - P_{ij})^2}}{4P_{ij}}$$

Omega variations with field

Pxx

x/y	-0.357	0.0	0.357
0.234	0.546231	0.551042	0.558245
0.0	0.535538	0.542301	0.550308
-0.234	0.543251	0.548048	0.555605

Pyy

x/y	-0.357	0.0	0.357
0.234	0.517816	0.523485	0.532094
0.0	0.515997	0.521932	0.529989
-.234	0.518687	0.524508	0.533185

Pxy

x/y	-0.357	0.0	0.357
0.234	-1.15e-3	-5.69e-3	-1.06e-2
0.0	-3.48e-3	3.08e-3	-4.68e-3
-0.234	-5.22e-3	-3.06e-3	1.51e-3

є

x/y	-0.357	0.0	0.357
0.234	0.991012	0.990524	0.989408
0.0	0.993101	0.992907	0.992751
-0.234	0.991206	0.992267	0.992896

Pxx, etc. moments have units of arc-sec^2

Є unitless

Field in object space degrees

Є ave = 0.9918±0.0013

4c3 variations with field

Pxx

x/y	-0.459	0.0	0.459
0.2315	0.229438	0.228884	0.22884
0.0	0.228737	0.229544	0.22766
-0.2315	0.228498	0.228167	0.22827

Pyy

x/y	-0.459	0.0	0.459
0.2315	0.221562	0.224083	0.227175
0.0	0.221620	0.223880	0.227381
-.2315	0.221563	0.224083	0.227172

Pxy

x/y	-0.459	0.0	0.459
0.2315	-4.8e-4	-3.90e-4	-2.50e-4
0.0	-4.3e-5	1.32e-4	1.19e-4
-0.2315	6.04e-5	2.80e-4	4.04e-4

є

x/y	-0.459	0.0	0.459
0.2315	0.994940	0.997249	0.999385
0.0	0.994586	0.997198	0.999911
-0.2315	0.994888	0.997216	0.999362

Pxx, etc. moments have units of arc-sec^2

Є unitless

Field in object space degrees

4c3

Є ave = 0.9972±0.0021

Omega

Є ave = 0.9918±0.0013

Pointing Control and Knowledge

Jeff Kruk

Pointing Knowledge - 1

- Nominal S/C performance requirements:
  - Control: p/y: 25 mas rms/axis, roll: 1 arcsec
  - Jitter: p/y: 40 mas rms/axis, roll: 1.6 arcsec (TBR)
  - Knowledge: p/y: 4 mas rms/axis, roll: 300 mas(TBR)
- Attitude Sensor suite:
  - FGS w/in payload
  - Two star trackers ~perpendicular to boresight
    - 2 arcsec accuracy
  - Gyro: Kearfott SIRU
    - AWN: 1mas/√Hz, ARW: 36mas/√Hr

Pointing Knowledge - FGS

- Outrigger SCAs on Imager focal plane
  - Supplemented by separate guider channel for slitless spectroscopy
- Plate scale: 180 mas/pixel
- FOV per SCA: 6.12 arcmin on a side
- Performance at 10Hz:
  - Noise Equivalent Angle at AB=15.5: 5-10 mas depending on filter
  - Noise Equivalent Angle at AB=16.0: 7-18 mas depending on filter
  - (when tracking 4 stars – can track more if necessary)
- For accurate revisits to a field, pre-select guide stars on the ground to ensure that the same stars are used for each revisit.

FGS cont.

- Guide star density at NGP:
  - Probability of finding N stars brighter than AB=15.5

AB=15.5	1	2	3	4
1 SCA	0.93	0.74	0.50	0.28
2 SCA	0.99	0.97	0.91	0.80

  - Probability of finding N stars brighter than AB=16.0:

AB=16.0	1	2	3	4
1 SCA	0.97	0.88	0.72	0.50
2 SCA	0.99	0.99	0.98	0.94

  - AB=16.0 gives adequate performance at 10Hz.

Telemetry downlink

- It is standard practice to downlink samples of sensor data; question is the sampling rate.
- Probably not worth downlinking full gyro rate, for example.
  - Not necessarily better than the FGS data if flexible modes in the instrument are important

- Can downlink full 10Hz FGS GS position data
- Can downlink Kalman filter output at its full rate, which indirectly provides the net results of the high-rate gyro data.
- *What knowledge is required?*

Present Status

- Have begun modeling integrated S/C, payload, ACS.
- FEM of Omega payload and S/C incorporated into simulator
- Includes both fixed and articulated solar arrays, fuel slosh model
- At early stages in tuning control law for slew-settle studies
- May need to iterate on star-tracker, rate gyro selection.